gulum ani distincte excavato, aliter directo; venis omnibus fere velut in *Taygetide*. Caput oculis nudis; palpis elongatis, extrorsum paulum porrectis; antennis tenuissimis, vix clavatis.

Amphidecta pignerator, sp. nov. Pl. IX. fig. 11.

Alæ supra fuscæ, area apicali anticarum et margine apicali posticarum obscurioribus; costa anticarum et angulo anali posticarum roseo-rubris: anticæ costa basali nigro liturata; maculis tribus discalibus albidis triangulum formantibus: corpus fuscum.

Alæ subtus pallidiores: anticæ minime violaceo tinctæ; apice fuscescente; area apicali et costa nigro lituratis; maculis velut supra, quartaque intermedia cuneata submarginali, albidis, plaga purpureo-fusca inclusis: posticæ albidæ roseo tinctæ, omnino fusco striatæ; apice niveo; angulo anali ferruginoso; lineis duabus mediis male definitis irregularibus; margine externo fuscescente; punctis sex discalibus albis nigro punctatis, serie undata positis: corpus ochreo-cinereum.

Exp. alar. unc. $2\frac{9}{16}$.

Hab. Ega. Coll. Bates.

Taken in the depths of the forest. Flight low and weak. Only a single specimen found. (Bates's MS.)

XLIX.—*The Method of Geology; being an Account of the introductory part of a paper on "The Laws which have determined the Distribution of Life and of Rocks," read before the Cambridge Philosophical Society, Nov.* 12, 1866. By Harry G. Seeley, F.G.S., of the Woodwardian Museum in the University of Cambridge.

In their distribution over the world, the materials of rocks which are accumulated under water, and the materials of organized bodies, obey the laws of physics. The forces that these laws relate to, in this subject, are:—in the first place, those inherent in the earth itself, such as gravity and attraction, on the one hand, and motion in the earth's crust; and, secondly, those acting on the earth from without, such as the heat received from the sun, and attractive forces which determine the earth's relations to the solar system. That is, everything is kept in its place by gravity, out of which it is moved by heat and the forms of energy into which heat is changed; while the area over which these forces operate in a given way is changed by movements in the earth's crust producing changes of land and water.

2. The motion of matter visible on the land is for the most part due to the sun's heat—hence being derived those distributing powers the winds and rain and rivers, in their various

forms, discharging rock-matter into the sea; while the settling-down of these materials upon the sea-bottom is the work determined by gravity. The motion of matter around the land is for the most part due to the tide-generating power of the sun and moon; but the arrangement of this matter on the sea-bottom is due to gravity.

3. The motion of living things on land is due primarily to the sun's heat distributing the individual species in zones of uniform temperature, modified by movements in the earth's crust producing distribution irrespective of temperature. The distribution of living things in water is due primarily to movements in the earth's crust, modified subsequently by the form of coasts, the abundance of life, and by temperature.

4. On the hypothesis of the earth having cooled from a fiery state, the surface-rocks would be uncrystalline granitoid substances, the denudation of which would furnish clays. But, as a matter of fact, everywhere beneath stratified formations some rock of a granitic character is found. Therefore, assuming all stratified rocks to be derived from the denudation of plutonic rocks, it is necessary to consider what stratified deposits such denudation can result in.

5. If the plutonic rock is crystalline, a granite may be taken as the type. It consists of quartz, felspar, and mica—speaking roughly, in the proportions of 25 per cent. of quartz, 55 per cent. of felspar, and 20 per cent. of mica. The quartz is heavy, and washes out in grains, which, left behind, form a deposit of sand. Hence, if granite were the only source of water-formed rocks, and only denuded by the sea, one-quarter of all known stratified rocks would be sands and sandstones. And therefore the quartz-grains (the sandstone to be, or that is) will form a belt near to and around the shore, and will always be indubitable evidence of near vicinity to land. And supposing the mica not to be decomposed, from its fine flaky character it will, according to circumstances of slope of sea-bottom, currents, &c., be carried either to the limit of the sand, and go to form a micaceous sandstone, or go beyond the limit of the sand, and form a micaceous clay (slate).

The felspar readily decomposes into a clay, setting free in addition a quantity of silica and potash or soda; and, from the extreme fineness of its particles, this clay is carried out to sea further than the sand, and surrounds the land as an outer belt, at least twice as broad as the sand-belt.

But if the denudation takes place on the land-surface by the agency of rain and running water, the major part of the sand will be left behind; and the detritus poured into the sea by the river will be chiefly the mud (*i. e.* the felspathic detritus) of the watershed.

If both forms of denudation go on together (as is often the case), the visible result is that the clay-band, as it approaches the river-mouth, extends out in a fan-shaped form, thinning off the further it is removed from the land; the great difference between the two sets of clays being that, whereas the coast-clay has its greatest extent in the line of the coast, the river-clay has its greatest extent in the line of the river, *i. e.* in a line at right angles to the coast.

Since all plutonic rocks are not granites, it may be that, in place of mica, there will be a more easily decomposed hornblende. Many forms of amphibole, like some kinds of mica, contain much iron. There can be no doubt that many ferruginous sandstones owe their iron to the decomposition of mica after deposition, just as it seems probable that many clay-ironstones were formed partly from the decomposition of hornblende at the time of deposition. Two other important constituents are lime and magnesia; and I know of no origin for these substances in nature except the plutonic rocks. Lime is to a great extent soluble in water, under sea-shore conditions, and is not precipitated by evaporation in an appreciable form where there are other deposits forming; hence it is that we usually find limestones near to shores where there is no denudation, and far out at sea beyond the limits of sedimentary deposits.

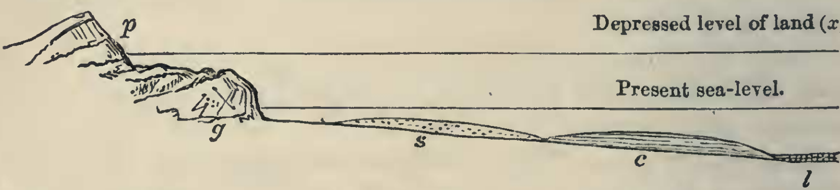
6. If, therefore, we find a magnesian limestone, it will be a reasonable inference that, if it could be followed over the old sea-bottom, it would merge into a clay on approaching land, that the clay would probably pass into a clay-ironstone, and this latter into a sandstone, beyond which must be an area without any deposit synchronous with these, which, however, would coexist in the same geological time, though of such different mineral characters, and these retained only under such limiting circumstances.

7. If beds have been already arranged in this order, which may be called the *necessary sequence of rocks*, and a cliff of them comes to be denuded, they are once more resolved into their elementary substances, and spread out as before. The reconstruction, however, may be generally detected by the pebbles and, it may be, extraneous fossils that it will contain.

8. Under ordinary circumstances the river-clay is distinguished from the shore-clay by its immense thickness; for, concentrating to a point the clay of a large area, it accumulates more rapidly than that resulting from tidal denudation; moreover it is more likely than any other kind of deposit to be continuous in the same area through several geological periods. The river-sand

is usually finer than shore-sand, and extends over a more limited area.

9. Sand, clay, and lime forming the sequence of rocks in horizontal order (*i. e.* in space), it must also follow that there will be a similar sequence in vertical order (*i. e.* in time). Thus, therefore, it follows that if (*g*) a syenitic coast is denuded, and the result is (*s*) sands, (*c*) clays, and (*l*) limestones, and the land (*g*) is depressed so that high-water mark stands at *x*, then, the



point from which the deposited materials are derived being carried further inland (*p*), they will not be carried so far out to sea; hence a sand will be deposited near shore and continuous with the old sand (*s*); a new clay will be deposited on top of the old sand (*s*), and a new limestone on the old clay (*c*). But if the land were to rise again, the place of origin for the deposited matter would go further out to sea, the new deposits nearest shore would be denuded, and sand be spread over the clay. If, then, there is a sequence of rocks like the Secondary series, it becomes extremely easy to determine all the changes in physical geography that took place while they were accumulating, while it is no less easy to predict what must be the representative of a formation in a district where the mineral characters have changed.

10. Of course, organic causes and evaporation may accumulate limestones without their having any relation to sands and clays, just as denudation of quartzites and sandstones may form sands which are not succeeded by clays, and as the denudation of volcanic rocks may form clays quite unconnected with sands and limestones.

11. The thickness of deposits in relation to time is to a large extent dependent on climate. In tropical regions where evaporation and the resulting rain are great, deposits of immense extent are formed. In cold countries, though of small extent, the deposits are liable, from the nature of the seasons, to a similar alternation of characters with those of tropical countries.

12. Every great *fault* changes the form and area of the sea-bottom, and therefore modifies the sequence of deposits within the disturbed area, producing unconformability if the fault is formed rapidly. There is every reason to believe that faults were as numerous in old geological times as in more recent pe-

riods; and therefore it is necessary to fix the ages of the faults to interpret accurately the sequence of rocks, and to discover therefrom the old physical geography.

13. From these considerations it follows that no deposit can be traced over a large area. And when the mineral character changes in a succeeding deposit, it follows that, at one end or the other, there will be no change of mineral character. Hence deposits cannot be identified or correlated over wide areas by this means. But this limitation of kinds of rock-material is evidence of change in physical conditions; and if uniformity of physical conditions can be determined, then it follows that there is a wider means than mineral character at command for co-ordinating water-formed rocks. Hence *strata can be identified and correlated by discovering the physical conditions which limited, determined, and changed their mineral characters, and changed the distribution of the fauna and flora of the given geographical area that they occupy.*

14. Nothing can be known of climatal conditions of the earth in past time, except from physical evidence. Such is the existence of coal; for, judging from the analogy of peat, there is strong reason for inferring that coal was formed under conditions of temperature not warmer than our English climate.

15. The most important physical phenomena for the elucidation of past physical geography are the thickness of the deposit over a wide area, the number of beds of which it consists, the relative sizes and characters of the constituent particles at different depths and in different districts, the amount and direction of the false bedding &c., the exact vertical and geographical position of fossils, &c. &c.

16. Just as the phenomena of water-formed rocks all owe their existence directly or indirectly chiefly to the sun's energy, so also do the phenomena interwoven with life. This has long been recognized by various eminent British and foreign physicists; and, in 1854, Prof. Huxley, in his memoir on the method of palæontology, asserted that organisms were but manifestations of applied physics and applied chemistry. Prof. Tyndall puts the generalizations of physicists in a few words: when speaking of the sun, it is remarked, "He rears. . . . the whole vegetable world, and through it the animal; the lilies of the field are his workmanship, the verdure of the meadows, and the cattle upon a thousand hills. He forms the muscle, he urges the blood, he builds the brain. His fleetness is in the lion's foot; he springs in the panther, he soars in the eagle, he slides in the snake. He builds the forest and hews it down, the power which raised the tree and that which wields the axe being one and the same."

Translated into other language, this means that since the sun is the chief appreciable source of energy on the earth, without which little or no motion would be manifested, it follows that organisms are storehouses in which the sun's energy has been accumulated in the form of work, and therefore that what are called grades of organization in classification are only ways of expressing the different degrees of energy that organic structures have stored up.

17. The manifestation of life on the earth is in every way most abundant in the tropics, plentiful in the temperate zone, and poor in genera and poor in species near the frigid poles of the earth. The exuberance of life, whether in individuals or species, over the whole earth, or upon one district in different seasons, coincides with the preponderance of heat. Heat acts indirectly for the most part; for when applied to an egg, it is partly converted into motion, causing the particles of the egg to move, and it enables them to enter into new chemical combinations, differentiating parts until the entire organism is formed. The energy which differentiates the individual egg is greatest at the tropics, where the differentiation of life is greatest.

18. Every organism is subject to two series of modifying agents:—1st, the external changes produced by the stimulus of the circumstances of existence; 2ndly, the chemical changes set up by contact of food with the viscera. Both of these sources contribute energy. When a mammal, for instance, moves, its work in part takes the form of motion; but the succession of falls which constitute walking or running convert a part of that motion into heat; this heat induces an expansion of the structures, enabling the nutritive fluid to permeate and circulate more rapidly, nourishing most the structures most used. Hence the development of parts with use. The development of the skeleton is chiefly due to differentiation of external functions; the development of the viscera is chiefly due to different functions imposed by food.

The viscera, therefore, are more liable to vary than the muscles; but their variation depends on the power of muscle and nerve in obtaining food. Therefore external changes are accompanied by internal changes. And since changes are inherited, they accumulate.

19. The individual being only liable to motion over so limited an area as to be practically fixed, yet experiences some results of enormous migrations from the change of seasons.

20. Since the heat of the earth may be assumed to be distributed approximately in zoned gradations of latitude, it will follow, from the preceding considerations, that if species were left to themselves for ever, the most highly organized would be at

the equator, the least organized at the poles. And since species diffuse themselves in the direction of least resistance, it will be along lines where the heat is uniform; so that homozoic belts (but for disturbing causes) will correspond with parallels to the equator.

The present distribution of land and water, and the geological evidences of its mutations, show that species are compelled to migrate north and south (as well as east and west), and so become subject permanently to different degrees of the sun's energy (and its product food), which, as was seen, cannot but produce permanent changes in their organization. Hence it follows that the same set of causes which introduce new rocks is also an instrument in introducing new species and new types, by changing the area of life.

21. When a portion of the sea-bottom is elevated so as to become land, the life which covered that area is displaced; that is to say, the group of life, from being continuous over an area, comes to surround a space which, so far as marine life is concerned, is a desert. The method by which this is accomplished is, that mountain ridges make divisions in the life-province; and then, just as the waters drain down the valleys of the land converging to an estuary, so also do the organisms drain off and converge with the separation of the waters: hence, but for disturbing causes, life will always be most abundant in species around the seaward terminations of the great areas of drainage. But, by the division of a group of life in this way, it happens (if the elevation is carried to a great extent) that each part of the old life-group becomes mixed with the new group on which it is compelled to encroach. If land already existing is still further upheaved, it can only happen that the life will migrate further away; so that the fauna which in one age occupied a given sea-bottom comes in a succeeding age to occupy an adjacent area.

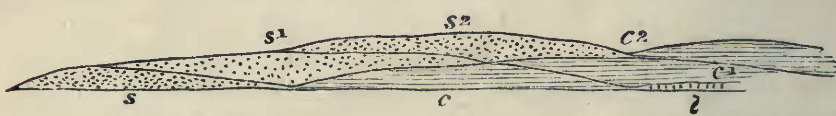
22. If a portion of the sea-bottom is depressed, the life that covered it migrates away, following the shore as it recedes. And also if a portion of land is depressed so as to become sea-bottom, the life that covered the adjacent area migrates over it, and life of the present age becomes diffused in the succeeding age over an adjacent area without admixture with any new forms, except such as may be produced by the changed conditions.

23. If elevation occurs so that a land-surface is enlarged, then the species already upon it migrate over the newly added area and down the mountain-sides, always diffusing most rapidly in the direction of least resistance.

24. If depression of a land-surface is going on, then the species are converging in space and becoming numerous relatively to their area, while they also ascend the mountains. If while the land sinks to the north it rises to the south, the fauna and flora come to occupy a more southern area*.

25. There being much reason for thinking that the deep waters of the ocean have a comparatively uniform temperature, it follows that the distribution of life in those regions will be less dependent on temperature than it is at the surface of the earth. Therefore the life of deep-sea limestones will have a wide range.

26. No elevation of land can take place without (as was seen in § 9) the deposits that were forming being continued over each other out at sea. Thus *s* is the sand formed near to the shore, and *c* the clay further out at sea; by elevation s^1 is formed over *s* and *c*, and c^1 is formed over *c* and *l*. By further elevation, s^2



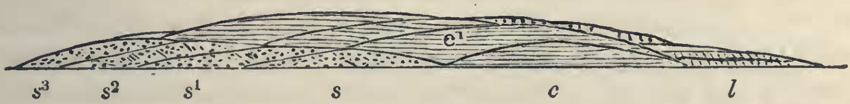
is formed over s^1 and over c^1, and of course a c^2 would be formed over c^1 and l^1, so that the *s*, s^1, s^2, s^3, &c. would appear to the observer of sections to form one deposit (for the divisions here marked would not exist in nature) extending uniformly over another deposit, *c*, c^1, c^2, which would therefore appear to be an older one; and as this deposit would extend over the *l* series, it would be inferred to be newer than that group. But, although that inference is correct in regard to the vertical section, obviously the *s* is older than the c^1, and much older than the c^2, though it appears to rest on the top of those deposits. And since by elevation the sea-area is changed, the fauna and flora continue to move in the direction of least resistance, which in this case being determined by uniformity of conditions, it happens that the fauna of *s* will migrate into s^1, and similarly will afterwards move into s^2; so that it will be impossible to identify the ages of these beds by fossils in the usual rough-and-ready way, or by superposition. Here identification of the strata can only be accomplished by the method given in § 13.

Often by elevation a fauna is compelled to migrate; and then the extension of a group of life assists greatly in connecting deposits in an adjacent area with those formed under other physical conditions, when we have discovered where the group came from.

* The migratory habits of birds are probably due to old changes in physical geography of this kind.

27. Under certain circumstances, when a group of life is driven to a new locality by elevation, it happens that the conditions of least resistance determine its course either over or under the group which previously occupied the ground; so that a gradation of life in zones of depth comes to result from the distribution of life in provinces.

28. No depression of land can take place without the deposit which was forming furthest out at sea appearing to be newer than the others. Thus here, *s, c, l* represent the typical sand-



stone, clay, and limestone. By depression s^1 is formed nearer to shore, and c^1 is deposited over *s* and *c*; and so the succession is continued, if the depression goes on, till the stratum s^3, s^2, s^1, *s* is formed under the *c* series, the *c* series in its turn being under the *l* series. Yet this apparent superposition gives a very erroneous idea of the age of the beds; and since the life follows the receding shore, it happens that the fauna of *s* is also found in s^3.

Hence it follows that neither in the rocks produced by elevation nor depression can the age of the beds be determined by superposition or by fossils.

29. Whenever a sandstone is superimposed on a clay, in some portion of the area the older stratified rocks will be denuded, if they were ever deposited there. Hence if such a sandstone contains extraneous fossils, they came from rocks which existed beyond the sandstone area, and on which the sandstone was not then being accumulated.

If the sea-shore is stationary, the majority of the fossils, accumulated from the life of the time, will be much worn.

30. The fauna and flora of the British Isles is not the only known fauna and flora. From the phenomena of elevation and depression, it follows that no fauna or flora can cover more than a fraction of the earth's surface at the same period of time; though it is quite possible for a fauna to migrate during a long period of time over a far larger area. And this is usually the significance of the correspondence between distribution of life in time and in space; and by a worldwide fauna is usually understood a fauna that has been split up by physical changes, so that at a few widely divided points a less or greater proportion of fossils (usually few) are found like those of the typical locality, but almost invariably mixed with others unlike those pre-

viously known (see § 21). There is no evidence that any fauna or flora ever was universal; physical considerations such as those detailed show that such a thing is impossible.

31. The life on the earth is conveniently divided into a number of groups called provinces, which have been produced by changes in physical geography modifying the natural distribution in zones of varying organization. They are the evidence of these physical changes and the means by which they may be discovered. Every life-province, whether on land or in the sea, is only a geological fauna or flora which has not become fossilized. Species have not been rooted to the area where found since their creation. Every geological fauna is only a life-province of the old sea in which the rock-material accumulated. If there is a change of life between two deposits, it indicates that a new life-province has migrated over the old one, and not necessarily that there has been any denudation or any break in time.

32. Since no life-province extends over a large area of the earth, it is impossible to identify distant geological formations by the similarity of their fossils.

33. Since much disturbance may occur in an area adjacent to that where deposition is going on, it may happen that two or three groups of life succeed one another in one place, while, near by, the first group of the three remains stationary. This is one of the many difficulties that render it impossible to get any definite results from percentages in fixing the age of beds. Nothing is known of the duration in time of either recent or extinct species; and for the percentage method to give accurate results, it must be assumed that every species has exactly the same duration in time, stopping at a given point; whereas it seems, from the case of some species sent to the antipodes for instance, that under changed conditions they may flourish better than ever. It is probable, too, that the distinctions at present in use between species add to these difficulties. And it is worth note that many genera survive from old palæozoic times; so that those periods, in a truer sense than that usually given to the term, might be called Eocene.

34. Palæontology is the zoology of past times. But stratigraphical geology is, as it seems to me, the only means by which either the past or the present distribution of life can be understood. Both these powers for research need to be used to discover the past mutations of the earth's physical geography, by coordinating which changes it is possible to correlate strata over wide areas, and to obtain materials for their classification.

35. No satisfactory classification of rocks can ever be made by fossils, for the reasons which have been given. Nor can a

classification true for any large area be made on mineral character.

But since the mutations in physical geography determine both the rock-material and the distribution of life, there is in them a philosophical basis for classification, which indicates the value alike of mineral character and of fossils. Yet classifications, though made on the most fundamental considerations, can never be carried from a typical locality all over the world, because the world has neither life, nor mineral character, nor stability of physical geography in common with the typical locality.

The proof, extension, and practical application of the cosmogeny here sketched will be given in the first volume of the 'Principles of Palæontology,' which is devoted to the dynamical geology of Britain.

L.—*Synopsis of the Species of American Squirrels in the Collection of the British Museum.* By Dr. J. E. Gray, F.R.S., V.P.Z.S., &c.

The species of American Squirrels are more difficult to define distinctly than those of Asia or Africa, arising from the various colours which the same species presents, even in individuals of the same family; thus Bachmann states, "Nothing is more common than to find the same litter composed of grey, black, and fox-coloured young."

Dr. Spencer Baird, in his well-studied essay on the Squirrels of North America, has shown that some species of the larger North-American Squirrels (as *Sc. vulpinus*) have a tendency to run into ferruginous varieties, and to have red bones, while other species (as *Sc. carolinensis*), of a yellow-grey colour, are very commonly affected with melanism, and have more or less black fur.

Both *Sc. vulpinus* and *Sc. carolinensis* vary, on the under surface of the body, from pure white to rufous or black.

Dr. Spencer Baird observes, as a general rule, that, where a squirrel exhibits any annulations of the hair on the fur of the throat or belly, it is a variety of some species which, in its normal form, has the under part either of a uniform white or reddish colour to the base, or only plumbeous at the roots.

The hairiness of the soles of the feet varies, especially in the species which inhabit the northern region of America, or which have an extensive geographical range there. Dr. Spencer Baird describes specimens of *Sciurus vulpinus* "with (1) the soles naked, (2) the soles hairy between the pads nearly to the end